Balloon Concepts for Titan

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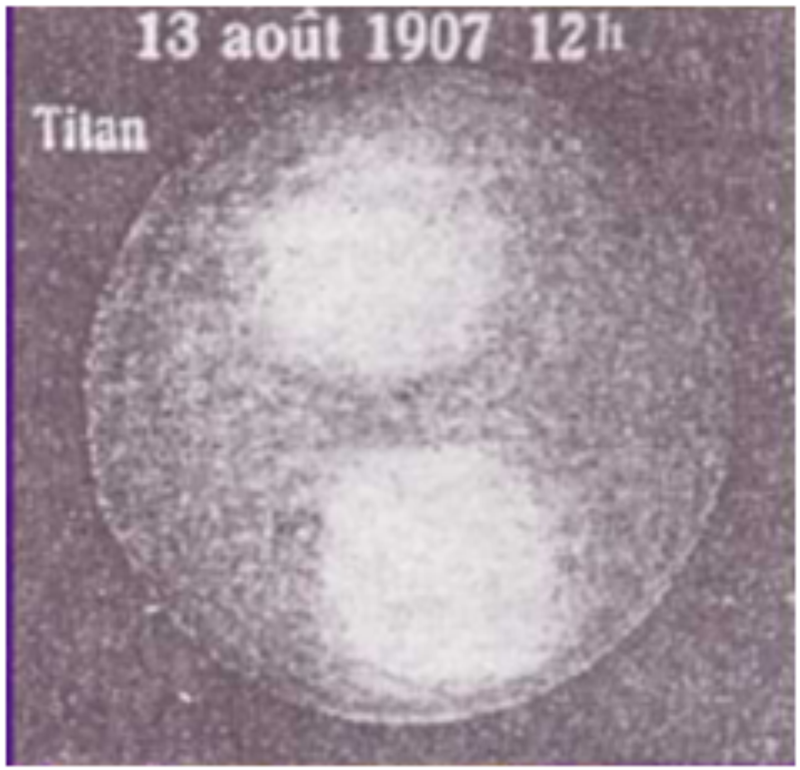
2007 - A Century of Knowing Titan is Special..

Drawing of Titan by Josep Comas Solà , 1907 using 38cm Mailhat binocular telescope at Fabra observatory, Barcelona



Shows 'limb-darkening' – suggestive of an atmosphere

Some Balloon History

3rd Century – Hot air balloons as toys in China

1767 – Joseph Black in Scotland suggests hydrogen-filled bags should rise in air.

March 1783 – Montgolfier brothers build paper balloon – hot air flight

December 1783 – Charles flies hydrogen balloon

1860s – Both sides use (gas) balloons for observation in American Civil War

1929 – Circumnavigation of the world by airship Graf Zeppelin

1950s – Genetrix/Moby Dick spy balloons. Project ManHigh

1960 – Modern Hot air balloon developed by Ed Yost

1978 – Montgolfiere balloons proposed for Titan by Jacques Blamont

1982 – SAIC/Friedlander study of balloon/airship concepts for Titan

1984 – Soviet Helium balloons fly around Venus, tracked by VLBI

1991 – Virgin Pacific Flyer hot air balloon flight Japan – Canada

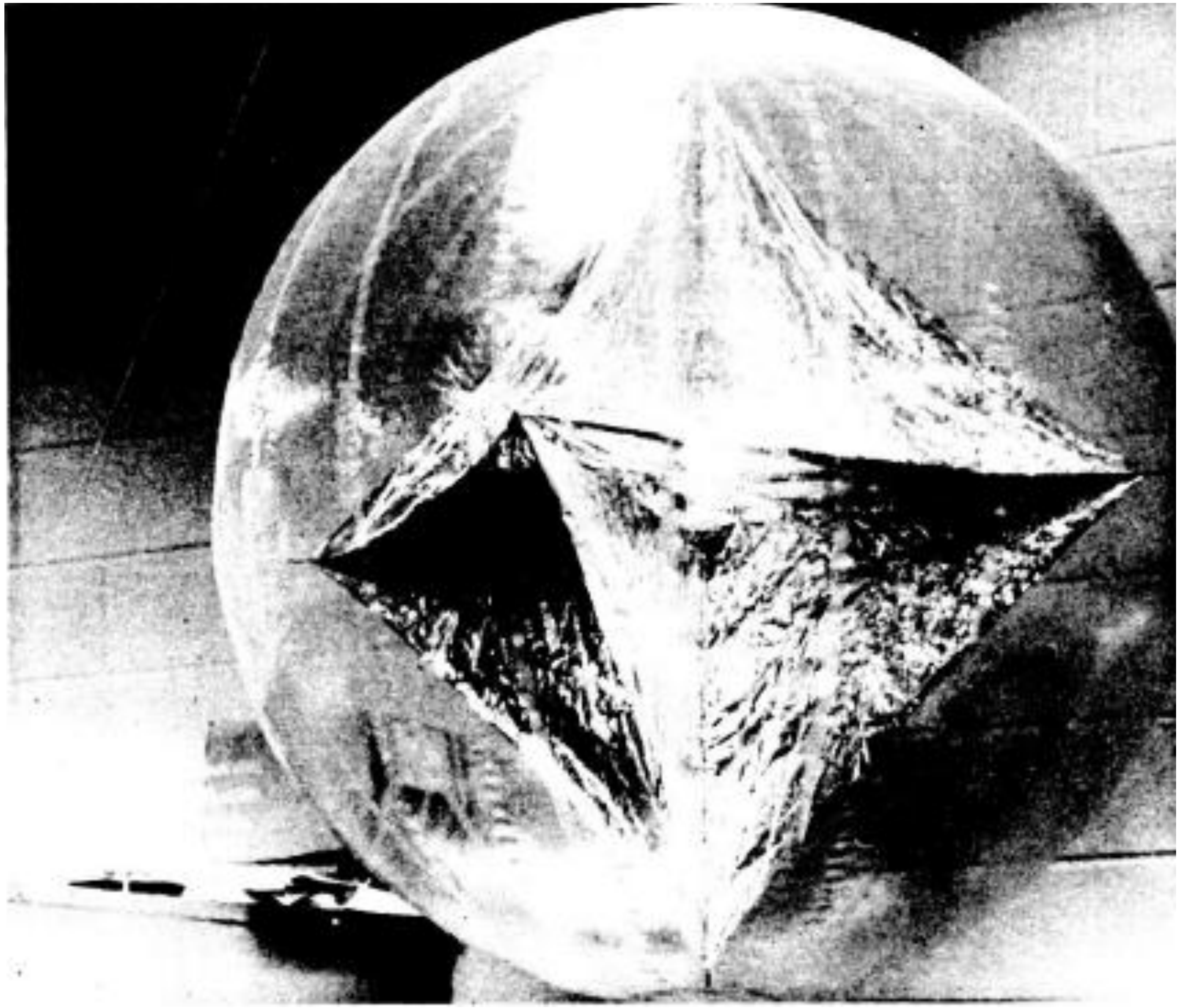
1997 - Balloon Experiment At Titan (BETA) study

1999 – Breitling Orbiter 3 (a Roziere) Circumnavigates world in ~20 days

2003-2006 GSFC TOAM, Langley, JPL Visions Mission, JPL TiPEX

A Titan Aerobot Menu

PASTA	PASsive TitAn balloon	Few kg. Helium. Released from descent probe or lander. No power, instrumentation or communication. Tracked via foil radar reflector or passive transponder (RFID) Could use condensible gas for altitude regulation.
ZORBA	ZOnal Recon BAlloon	~50kg. One RPS (~100W). Montgolfiere or buoyant gas. Omnidirectional comm (DTE and relay) Payload ~5kg : USO for groundbased tracking. Simple camera system. Altimeter. Meteorology (Sky brightness, Pressure, Temperature, Methane humidity) Minimal (no?) commanding.
TABI	TitAn Balloon Investigation	~100kg Montgolfiere. Active altitude control. 1-2 RPS 30kg payload? Camera system, ground-penetrating radar. Aerosol collector and analysis laboratory. Meteorology.
TABASCO	TitAn BAlloon Survey and Collection of Organics	Similar to 2005/6 JPL 'TiPEX' study ~200kg floating mass 2 RPS double-wall Montgolfiere. Active altitude control Steerable antenna for data relay Tether/penetrator sample acquisition system and organic analysis laboratory. IR spectrometer, camera system, gound penetrating radar, meteorology, etc.
TALE	Titan Airship Latitude Excursion	Similar to 2005 JPL and Langley Visions studies. Buoyant gas airship with propulsion giving capability to traverse to different latitudes. 2 RPS. Steerable antenna for data relay Tether/penetrator sample acquisition system and organic analysis laboratory. IR spectrometer, camera system, gound penetrating radar, meteorology, etc.



1m-diameter Rocket-Deployed Balloon with Radar reflector (Peterson, 1965)

Helium Balloon at Titan

Advantages

Helium or hydrogen offer much higher lift / volume than hot air.

Envelope can be much smaller. Inflation probably more straightforward.

Light gas balloons are the only effective way of attaining high altitudes (e.g. 80kg payload at 60km altitude requires 13m dia balloon 202kg float mass ; 296kg delivered mass)*

Disadvantages

-For low altitudes especially, helium mass required is not small (dominates over envelope mass). Situation is exacerbated by tankage required for gas. (e.g. 80kg payload at 8km requires 4.2m balloon ; float mass 127kg ; delivered mass 191kg)*

- While low temperatures will lead to slower diffusion, helium balloon is ultimately doomed by loss of gas via diffusion and/or leaks

- No possibility of commandable altitude control   (some limit-cycling by condensible fluid could be achieved)

* 0.1 kgm^{-2} envelope. 2kg/kg Tankage

Hot Air Balloon at Titan

Terrestrial hot air balloons limited by envelope temperature : thermal power available from burners is ample, operated at low duty cycle.

Titan balloon is power-limited. An interesting theoretical situation – it turns out in an idealized analysis with thin-wall balloon (no insulation effect) that for a given thermal power etc. a maximum payload mass exists. (The maximum occurs when envelope mass equals payload mass – any increase in balloon diameter just means a heavier balloon).

For one MMRTG (2kWth) absolute maximum payload at 8km is 195kg, 23m dia.*

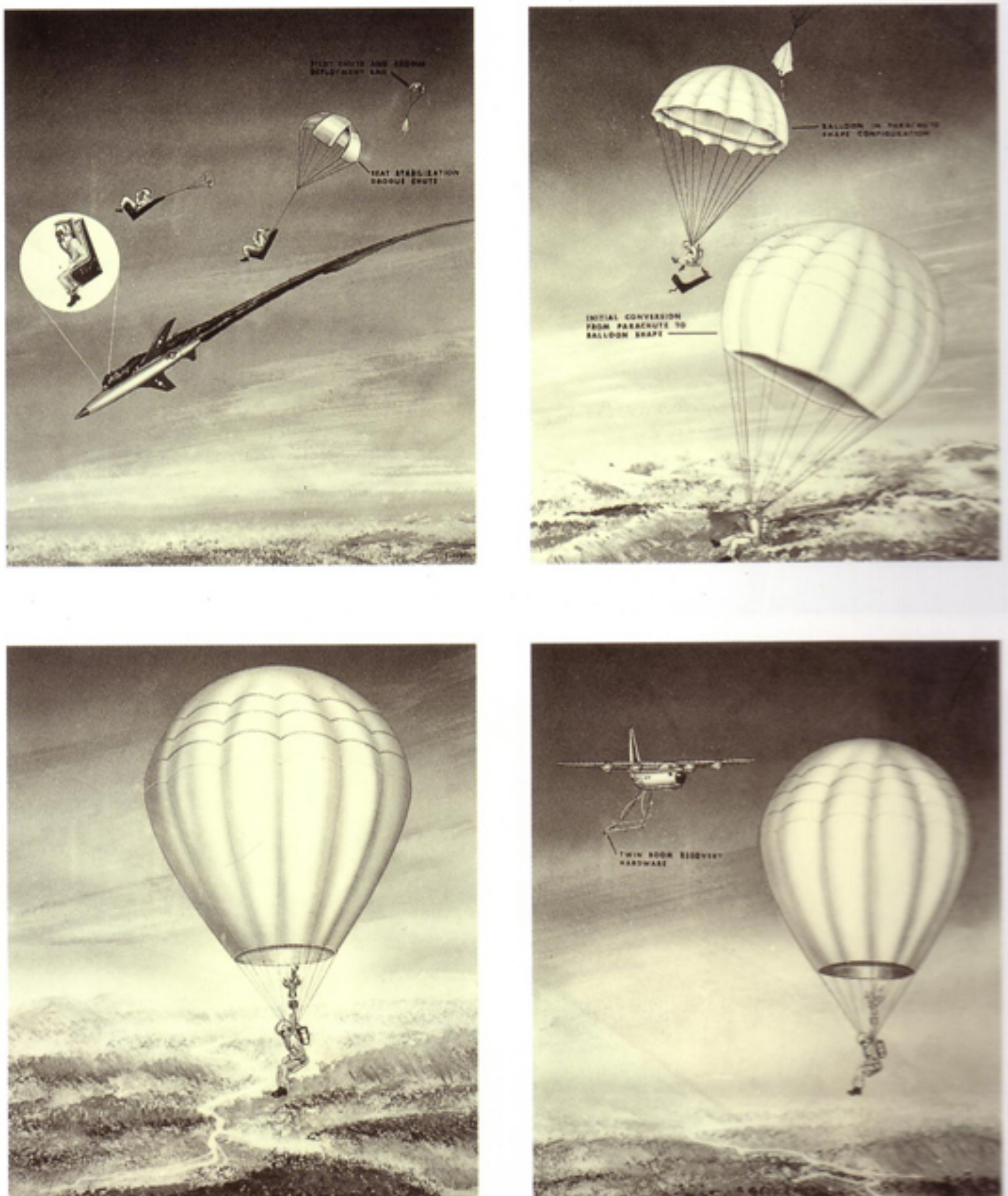
However, we derate substantially to have robust margins (e.g. terrestrial experience is that ~25% of heat supplied is lost at vent, more if manoeuvring. Real balloons have ~20% more area than if they were actually spherical, etc.)

e.g. 80kg payload at 8km with 1.5kW requires a 9m+ balloon, ΔT~5K. Delivered mass ~110kg. With 10.5m balloon it would still float (at ~1km) with 1.2kW.

NB Theoretical analysis shows payload mass varies as inverse of envelope specific area A, but inverse square of heat transfer coefficient h. Worth it to spend 4x envelope specific area to halve the heat transfer (e.g. insulate part of envelope, double wall envelope etc.)

* h=1 Wm^{-2}. A=0.1 kg^{-2}.

Over 7000 licensed balloons in the USA – carrying from 1 – 12 persons.



Modern Hot-Air Ballooning owes its origins to the Cold War.

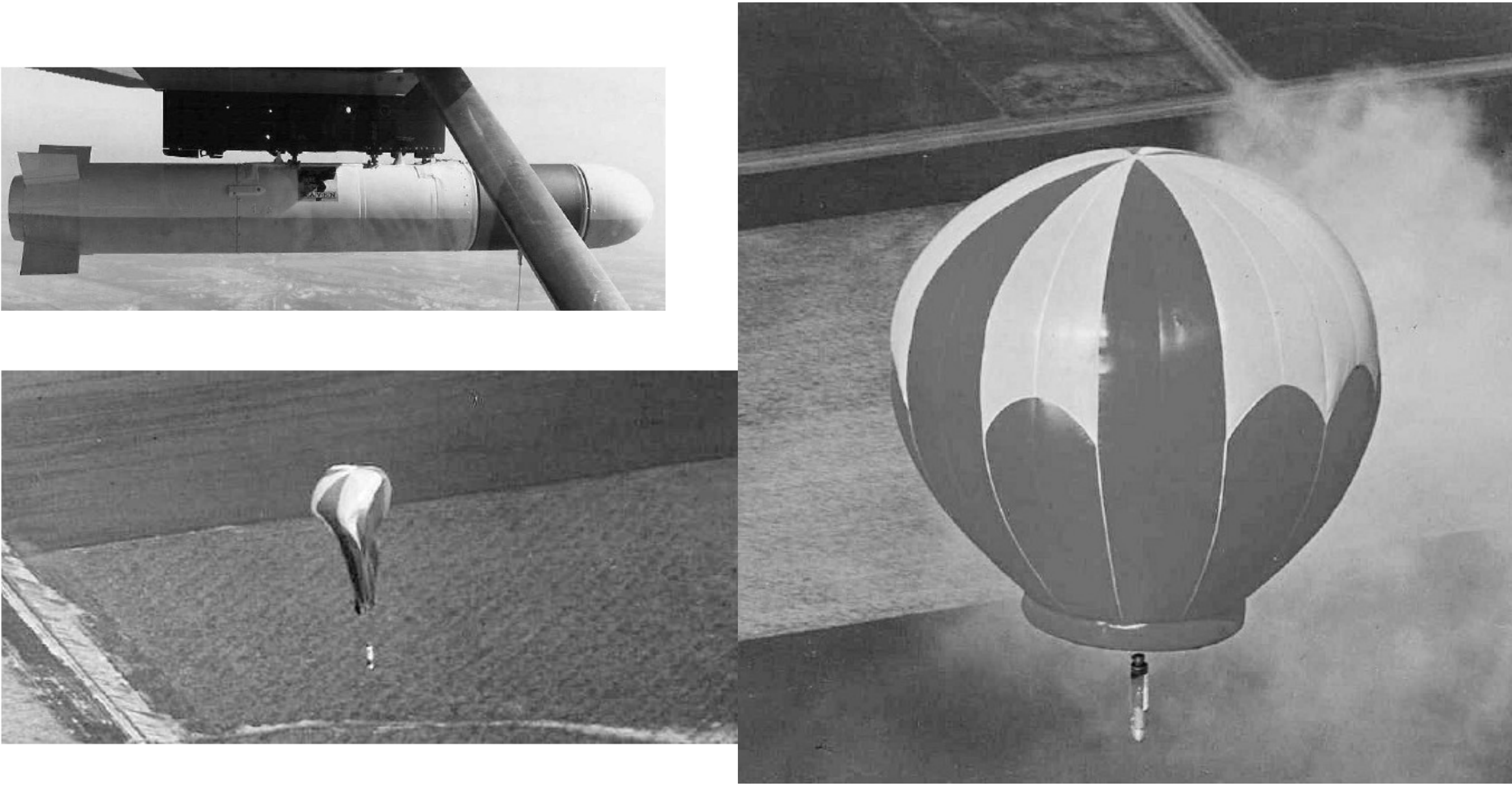
One concept was for a Pilot Escape System that would keep a stricken pilot aloft long enough to be retrieved in mid-air, without landing in hostile territory.

Also exploration by Ed Yost of hot air for balloons used to transport leaflets across Iron Curtain.

Led to key innovations – propane burner, rip vent, nylon envelope etc.

Figure from D. Owen (Lighter than Air, 1999, p79

Source Rekwin Archive



Airborne jamming pod – deployed in canister from aircraft, inflating in mid-air, heated by pyrotechnic charge and in level float.

Images from J. Nott, Ballutes- Launching Aerobots without Compromises, 4th International Planetary Probe Workshop, Pasadena, CA. August 2006

(Photo credit: Rekwin Archive)

Hot air balloons are damage-tolerant.

Envelopes usually rated for 600 hours flight time (i.e. ~100 inflation/packing cycles.) Rating is at 125^{o}C – sealant degrades less quickly at lower temperatures. (Graceful degradation – damaged envelope just requires more fuel to fly – retirement of envelope usually an economics rather than safety consideration)

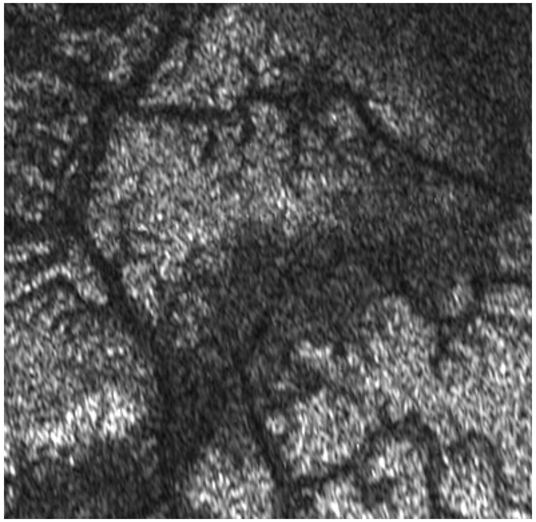
Continued Airworthiness Requirements allow ½ -inch holes in upper part of envelope to be repaired at annual inspection. 3/4-inch holes require repair before next flight. Holes in lowest 10 feet are permitted to remain unrepaired.

Titan balloon need be inflated only once (plus a few times for ground testing) and can be warm when this is done. Balloon fabric will operate at ~110K at Titan.

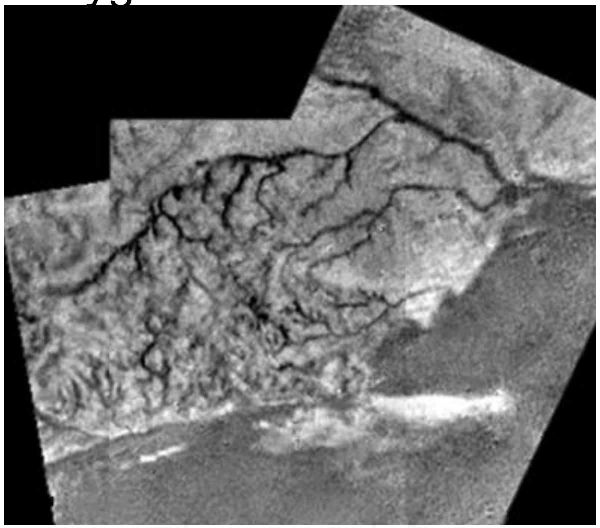
No UV degradation of fabric to worry about at Titan.

Orbiter – Balloon – Lander : A Multiscale Architecture for Exploring a Diverse Multiscale Surface

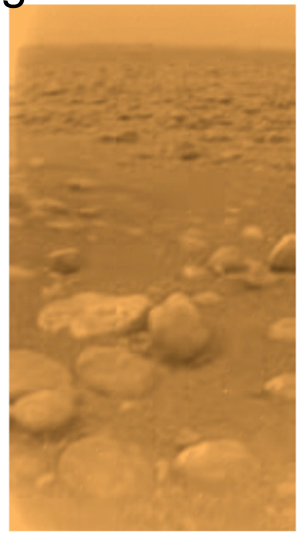
T28 SAR ~ 35km



Huygens DISR ~4km



Huygens DISR ~ few m

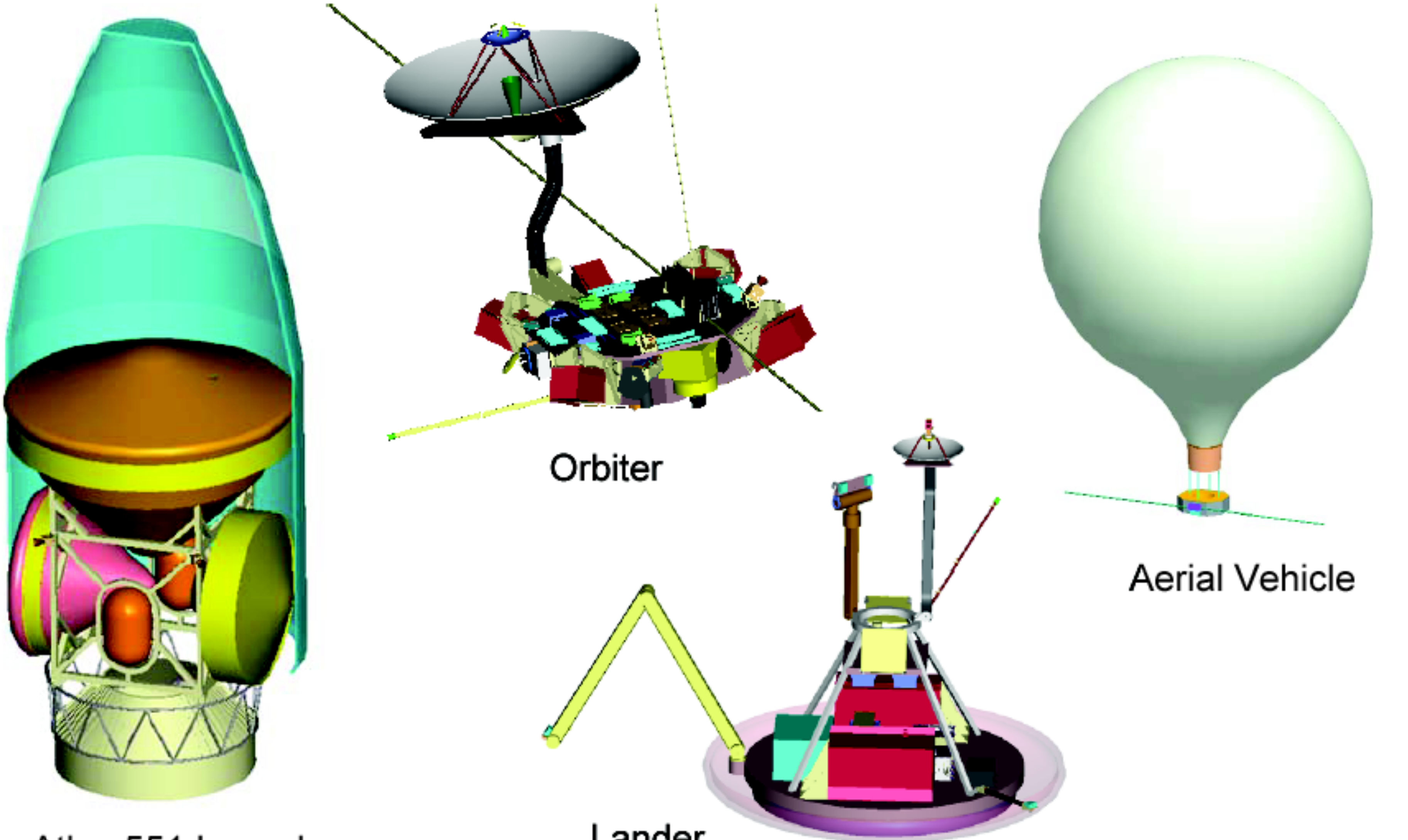


To understand the processes shaping Titan needs information on all scales – e.g. for fluvial processes need large-scale networks and topography, mid-scale observations to understand e.g. runoff threshold and floor fill, and small scale to characterize sediment itself.

Atmosphere (via optical scattering and enforced high altitude of orbiter) makes mid-scale (~1-10m resolution) difficult to acquire e.g. by HiRISE-type instrument. Lander would not see wide diversity of terrain during descent.

An aerial platform like a balloon bridges the scale gap – wide coverage at high resolution. Reduces risk for future lander missions by characterizing terrain hazards.

Orbiter, Lander, Aerial Vehicle



Aerial Platform Payload

Instrument	Mass (kg)	Power (W)	"Representative" Heritage
Subsurface Radar	8	30	MRO – MARSIS
Met Package	2	2	MSL
TDL Spectrometer (inc. Nephelometer)	4	40	MSL
Visible Imager	1	4	MS98 – MARDI
Near-IR Spec/Atmospheric Optics Monitor	7	10	Huygens – DISR
Altimeter	3	10	TBD
TOTALS	25	96	

Science Trace Matrix (still being iterated for consistency with objectives document) guides architecture & payload selection

(Payloads are strawman only – not only set that meets goals)

Objective	Investigation	Measurement
1. Titan's Origin and Evolution. What is the original composition of rocks and ices that formed Titan and what is the extent of differentiation and geochemical processing that has occurred since the initial formation? How do we explain the similarities and differences between Titan's structure and that of other solar system bodies? What is the original composition of rocks and ices that formed Titan and what is the extent of differentiation	Differentiation, internal structure, heat flow and magnetic field	Measure rotation parameters (pole position, libration etc.)
		Low Order Gravity Field (J2, C22)
		Low Order Topography (polar/equatorial radii)
		Vector magnetic field around Titan
		Detect presence of seismic activity (tidal and tectonic)
		Measure normal seismic modes
	Geochemical constraints on composition and exchange	Measure noble gases and isotopes (esp Kr, Xe)
		Detect Ammonia in surface material
		carbon, nitrogen isotopes in surface/atmosphere reservoirs
		Detect morphological indicators of exchange (vents etc.)
		Measure D/H in surface material
		Composition of gases released from vents etc.
	Determine thickness, conductivity etc. of subsurface ocean and thickness and rigidity of crust	Measure induced magnetic field
		Detect seismic reflections within crust
		Measure normal seismic modes
		Detect subsurface radar reflections
		Measure variations in rotation period
		Regional scale topography (1km/m)
		Measure changes in gravity field (k2)
		Measure orbital changes in topography (h2)
2. Titan System Science. How does Titan function as a system? How do we explain the similarities and differences between Titan and other solar system bodies in the context of the complex interplay of the geology, hydrology, meteorology, and aeronomy present in the Titan system	Characterize landscape modification processes today and through time (erosion, impact, tectonics, fluvial, lacustrine etc.)	Map global topography (1km/10m)
		Measure dynamic lake topography (10km/1m)
		Measure regional topography (100m/1m)
		Regional morphology (1m)
		Global morphology and texture (100m)
		Global near-IR albedo (100m)
		Regional variations of reflectance spectrum (10m)
		Local-scale morphology (0.1-0.01m)
		Regional subsurface structure (10km/100m)
		Regional subsurface structure (1km/10m)
		Local subsurface seismic structure
	Determine volatiles and condensates in the atmosphere and surface	Determine composition of surface volatile inventory
		Global distribution of minerals and condensates
		Determine volatile distribution in atmosphere
	Determine 3-D circulation of the atmosphere and local dynamics to understand transport and its role in chemistry, precipitation etc.	Obtain vertical temperature soundings
		Measure superrotating zonal winds
		Determine mean meridional circulation
		Measure profiles of organic gas abundance
		Measure topography boundary (100km/100m)
		Measure time-series meteorology
		Determine cloud distribution, morphology etc.
		Measure surface temperature distribution
		Measure deposition of sunlight vs. (lat/altitude)
		Measure optical properties of aerosol particles
		Measure number density and size of aerosol
	Atmosphere/space interaction - loss of materials, sources of free energy and heat for driving chemistry and dynamics. Determine chemical pathways to tholin formation	Measure vector magnetic field
		Measure high-energy magnetospheric electrons
		Measure thermal electron density and temperature
		Measure ion velocity distribution
		Measure high-molecular mass ion composition
		Measure high-molecular mass neutral composition
		Measure escape flux of suprathermal neutrals
		Detect high energy neutrals and ions from interactions
		Measure flux and energy of cosmic rays
3. Organics and Life's Origins. What is the extent of, and what are the processes responsible for the complexity of Titan's organic chemistry in the atmosphere, within its lakes, on its surface, and in its putative subsurface water ocean and how does this knowledge contribute to our understanding of the origin of life in the solar system?	Determine the extent of organic chemical evolution that could lead or has led towards life	Determine CHONPS elemental composition of surface
		Determine surface composition of complex organics
		Characterize physical state of organics
		Measure isotope ratios of C/N/O of surface organics
		Measure chirality of organic compounds
	pathways leading to tholins and their deposition and modification on the surface	Measure chemical abundance of gases in atmosphere
		Measure chemical composition of particulates
		Measure sources of free energy
		Measure atmospheric thermal structure with latitude
		Measure the abundance of radioactives in surface materials
	Determine if surface chemistry (esp. aqueous) has occurred	Determine CHONPS composition of modified deposits
		Determine composition of complex organics in special sites
		Identify potential chemical modification sites from mapping
	Determine role of abiotic synthesis on minerals and interior (serpentinization)	Determine presence of inorganics in surface material
		Determine CHONPS composition of venting products
		Determine composition of complex organics in vent products
		Measure isotope ratios of C/N/O of vent products

Conclusions

Balloons at Titan are easier than balloons anywhere else

A balloon type exists for any risk posture

For Titan, balloons must be passive, very short-lived, or RTG-powered. Available RTG types 'quantize' design options – small RTGs would permit new options

For low-altitude, large payload, RTG-montgolfiere is particularly efficient, and can be made manoeuvreable via altitude control, or even by propulsions

Science value from nonlanding balloon judged by NASA-appointed Flagship SDT as less than from a lander.

But

- significant science nonetheless (esp imagery, spectroscopy, ground-penetrating radar, winds)
- balloon-scale (~1m) imagery impossible to get from orbit. Probably essential for determining trafficability/landing safety beyond dunes / lakes
- consider as technology experiment (cf MFEX/Sojourner)

Baseline Flagship Mission Architecture is Orbiter + Lander + Balloon